Soil Tester System For N, P, K Micronutrients Detection

Dissertation submitted to
Visvesvaraya National Institute of Technology, Nagpur
In partial fulfilment of the requirements for the award of the degree

Master of Technology
in
VLSI Design

by

Mahesh Shankarrao Salame

(MT23MVD005)

Under the guidance of

Dr. Ganesh. C. Patil

Center for VLSI and Nanotechnology
Visvesvaraya National Institute of Technology
Nagpur 440010, (India)

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Declaration

I **Mahesh S Salame** hereby declare that this dissertation titled " **Soil Tester System For N,P,K Micronutrients Detection**" is carried out by me in the Department of **Center for VLSI and Nanotechnology** of Visvesvaraya National Institute of Technology, Nagpur. The work is original and has not been submitted earlier whole or in part for the award of any degree/diploma at this or any other Institution / University. no part of this work shall be published anywhere without written permission of the Dr. Ganesh C.Patil.

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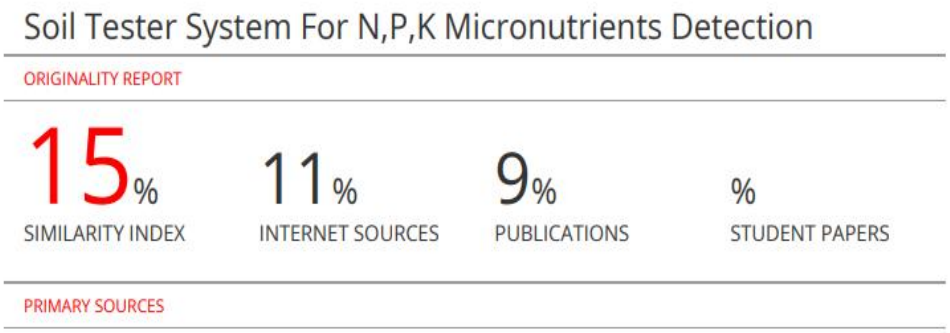

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Mahesh S. Salame

Abstract:

The need for sustainable agriculture is growing rapidly in response to increasing food demand and environmental challenges. One of the critical components of efficient farming is soil health, which is significantly influenced by nutrient content especially Nitrogen (N), Phosphorus (P), and Potassium (K). Traditional laboratory methods for testing these nutrients are time-consuming and often expensive, limiting their accessibility to farmers. This thesis presents the design and development of a cost-effective and real time portable soil testing system for the detection of NPK micronutrients using chemical sensor and msp430f5529 technology. The system integrates soil nutrient sensors with a microcontroller-based processing unit and a display interface to provide real-time analysis of soil nutrient levels. The proposed solution aims to enable farmers to make data-driven decisions for precise fertilizer application, promoting better yield and environmental protection. The device was tested with real soil samples, and the results were compared with standard lab methods to validate its accuracy and reliability.

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Abbreviations:

CV: Cyclic voltammetry

PET: poly ethelene tetraphtalate

PP: Poly propelene

SP: Screen Print

SPE: Screen print Electrode.

ISM: Ion sensing Matrial

CE: Collector electrode

WE: Working electrode

RE: Reference electrode

EIS: Electrochemical impedance spectroscopy

MSP430F5529L

LCD 16*2

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1

INTRODUCTION

1.1 Soil Pollution:

When harmful substances such as chemical fertilizers or pesticides enter the soil, they degrade its quality and can make it unsafe for plant growth and potentially harmful to human health. Consuming food grown in contaminated soil can pose risks to our well-being. Despite the vastness of the Earth's land surface, only a small fraction—about 10 to 11 percent—consists of fertile soil suitable for agriculture. Even within this limited area, factors like challenging terrain, urban development, and varying climate conditions further restrict the land that can be effectively used for farming.

1.2 Causes of Soil Pollution:

Agricultural soil pollution arises when the land is contaminated by substances such as chemical fertilizers, pesticides, and agricultural waste. Excessive use of these chemicals in farming can lead to the buildup of toxic compounds in the soil, which diminishes soil fertility and disrupts the balance of beneficial microorganisms. This degradation not only reduces crop productivity but also threatens the health of animals and people who rely on the land for food and habitat. Additionally, poor management of agricultural waste and the application of untreated wastewater contribute to the worsening of soil pollution, making it a significant environmental issue.

There are some major resources of pollution which is represented by Figure 1.1

- Industrial waste disposal
- Electronics waste
- Agricultural Chemical
- Mining Activities
- Sewage and Wastewater

Figure 1.1 How soil is contaminated

1.2.1 point source pollution:

Point source pollution in soil occurs when contaminants originate from a specific, easily identifiable location, such as a factory discharge pipe, a leaking storage tank, or direct sewage dumping onto land. These sources introduce high concentrations of pollutants—such as heavy metals, hazardous chemicals, oils, or untreated waste—into the soil at a particular spot. As these substances accumulate, they disrupt the soil's natural chemical and biological processes, often resulting in decreased fertility, the destruction of helpful soil organisms, and land that is unsuitable for farming.Over time, these pollutants can migrate deeper into the ground, potentially reaching and contaminating groundwater supplies and harming nearby ecosystems. While point source pollution is generally easier to identify and control than diffuse, non-point sources, the damage it causes can persist for years and may require significant remediation to restore the soil's health

.1.2.2 Non-point source pollution:

Non-point source soil pollution arises when contaminants are introduced into the soil from numerous, dispersed origins, making it difficult to pinpoint a single source. Unlike pollution from a specific site, this type of contamination is spread over wide areas by natural forces such as rainwater runoff, irrigation, or wind. Typical contributors include the over-application of fertilizers and pesticides on agricultural land, runoff from roads and construction zones, scattered urban litter, and waste from livestock in open fields. As these pollutants are transported by water or wind, they gradually accumulate in the soil, leading to a decline in soil health. This form of pollution can lower soil fertility, raise the concentration of harmful substances, and upset the natural balance of nutrients and soil organisms. Because non-point source pollution is diffuse and challenging to monitor or regulate, it represents a major obstacle for environmental management. Addressing this issue requires the adoption of improved agricultural techniques, thoughtful urban development, and increased public awareness to help reduce the spread of soil contaminants across large areas.

1.3 Impacted Different Soil Sources:

Soil Organic Carbon (SOC) Loss:

Transforming natural landscapes into farmland, frequent plowing, and burning plant material all contribute to the depletion of soil organic carbon. This loss not only reduces the soil's ability to retain water and nutrients but also leads to a decline in soil fertility. Additionally, lower SOC levels can increase the release of greenhouse gases into the atmosphere, contributing to climate change.

Heavy Metal Accumulation

Both industrial operations and agricultural practices can result in the buildup of heavy metals such as lead, cadmium, mercury, and arsenic in the soil. These metals are harmful

to soil organisms and can be absorbed by crops, eventually entering the food chain and posing health risks to humans and animals.

Physical Degradation

The use of heavy farming equipment, excessive tillage, and expansion of urban areas often lead to soil compaction, erosion, and the removal of nutrient-rich topsoil. These changes reduce the soil's ability to absorb water and support healthy plant growth, making it more susceptible to further degradation.

Chemical Degradation

Applying large amounts of fertilizers and pesticides can disrupt the natural chemical balance of the soil. This practice may alter soil pH, reduce populations of beneficial microorganisms, and cause nutrients to leach away, resulting in contamination and decreased soil productivity.

Biological Degradation

Soil pollution and physical disturbances can diminish the diversity and activity of soil microbes. This loss of biological life weakens the soil's natural resilience and reduces its capacity to provide essential ecosystem services, such as nutrient cycling and disease suppression.

Effects of Soil Pollution

The impact of soil pollution is becoming more pronounced with the growth of industries, advances in agricultural technology, and increased chemical usage. Contaminated soil can have far-reaching effects, harming human health, damaging the environment, and negatively affecting plants, animals, birds, and other living organisms. As pollution levels

rise, the risks to ecosystems and public health continue to grow, underscoring the need for better soil management and pollution prevention strategies.

1.4 Prevention of Soil Pollution:

Preventing soil pollution is vital for maintaining environmental quality, supporting agriculture, and safeguarding public health. Effective prevention involves reducing the reliance on chemical fertilizers and pesticides by adopting sustainable farming practices that enhance natural soil fertility. Proper waste management—especially of industrial and agricultural byproducts—is essential to keep harmful substances from entering the soil. Reforestation and soil restoration techniques help repair degraded land, while public awareness campaigns encourage responsible behaviors that protect soil health. Additional strategies include recycling organic waste, using organic fertilizers, and enforcing strict regulations on industrial waste disposal. These actions, when combined, help maintain soil quality and fertility, ensuring that land remains productive and healthy for future generations.

Macronutrients	Standard efficency %	Remarks
Nitrogen (N)	0.1% -- 0.5%	Poor growth of plant
Phosphorus (P)	0.01% -- 0.2%	Affect root development
Potassium (K)	0.1% -- 0.3%	Regulate water and disease

Table 1.1 Standard NPK Percentage of Soil

It is important for everyone to understand the characteristics of good soil, how to assess its quality, and methods to remove contaminants. This knowledge is crucial for safe food production and overall well-being. Soil quality can be checked through several testing methods: nutrient tests (to detect levels of nitrogen, phosphorus, and potassium), chemical tests (such as measuring soil pH), and salinity tests (by evaluating electrical conductivity to determine salt content). Regular soil testing allows for timely interventions to address imbalances and remove pollutants, supporting sustainable agriculture and food safety. Beyond the obvious impacts, soil pollution also results in indirect costs that are often overlooked. These include reduced agricultural output, which can drive up food prices and contribute to food insecurity. Remediation of contaminated soils can be expensive, and long-term ecosystem damage can disrupt biodiversity and essential natural processes like nutrient cycling and water filtration. Health issues arising from exposure to polluted soils can also increase medical costs and diminish quality of life. These indirect effects underscore the importance of proactive soil pollution prevention and the adoption of sustainable land management practices.

1.5 Soil Micronutrients:

Micronutrients are crucial elements that plants need in only trace amounts—typically measured in micrograms to milligrams per kilogram of soil. Despite their minimal presence, these nutrients are indispensable for healthy plant growth, development, and overall productivity. While micronutrients are required in much smaller quantities compared to macronutrients such as nitrogen, phosphorus, and potassium, their importance is equal when it comes to supporting key physiological and biochemical processes within the plant. Deficiencies in micronutrients can lead to stunted growth, poor yield, and increased susceptibility to diseases, highlighting their essential role in maintaining robust and productive crops.

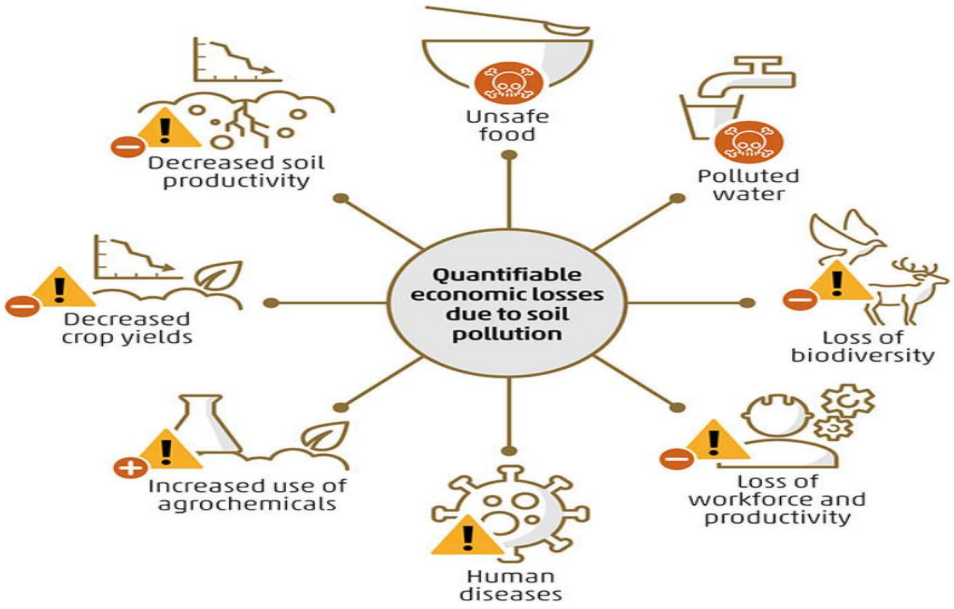

Figure 1.2 Environment Soil Pollution

1.6 Sensor:

A sensor is also known as transducer that is an apparatus or element that recognizes or quantifies a physical quantity and transforms it into an electrical or digital signal. internal blocks of sensor explained in Figure 1.3 .Sensors are used to track and collect data about the immediate environment or certain situations. They are widely used in many industries, including engineering, science, agriculture, business, the medical area, and consumer electronics.

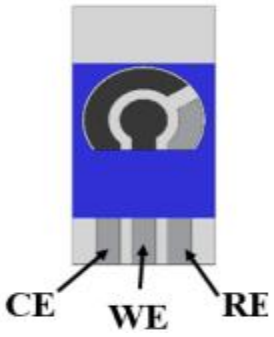

Figure1.3 Block diagram of Sensor

A paper-based screen-printed electrode (SPE) sensor is an innovative, low-cost device designed for the detection of potassium ions in soil. This sensor is fabricated by printing conductive inks, such as silver/silver chloride and carbon, onto a flexible polyethylene terephthalate (PET) substrate using a screen-printing process. The sensor consists of three electrodes: a working electrode (WE), a reference electrode (RE), and a counter electrode (CE). The working electrode is coated with an ion-selective membrane containing valinomycin, a compound known for its high selectivity toward potassium ions.

During operation, a small volume of soil extract is applied to the sensor. The potassium ions in the sample interact with the valinomycin membrane on the working electrode, leading to an electrochemical response that is measured using techniques like cyclic voltammetry. The resulting current or potential changes are directly related to the concentration of potassium in the soil sample.

1.7 This SPE sensor offers several advantages:

Affordability: The use of screen-printing and inexpensive materials keeps production costs very low, with each sensor costing only a few rupees.

Portability and Ease of Use: The compact design and simple measurement process make it suitable for on-site soil testing, eliminating the need for complex laboratory equipment.

Sensitivity and Selectivity: The valinomycin membrane ensures the sensor responds primarily to potassium ions, providing accurate readings even in the presence of other soil constituents.

Scalability: Multiple sensors can be produced simultaneously on a single PET sheet, supporting large-scale deployment.

The sensor's performance has been validated through tests on soil samples from different locations, demonstrating consistent sensitivity and reliable detection of potassium across various soil types. This technology represents a significant step forward in providing farmers and agricultural professionals with rapid, accurate, and affordable soil nutrient analysis, supporting better crop management and sustainable agricultural practices

1.7 Type of sensors:

There are many different Types of sensors that may be used as mentioned that is in Fig. 1.4. Each of which is intended to find and measure particular physical measurements or characteristics. Following are a few typical sensor types:

Chemical sensor: A chemical sensor is a device that detects specific chemical compounds or ions in a sample and converts this chemical information into a measurable electrical signal (such as voltage or current).

Pressure sensor: Sensor for measuring and detecting changes in pressure, Piezoresistive, capacitive, and strain gauge sensors are a few examples.

Light sensor: calculates ambient light levels or light intensity. Photodiodes, phototransistors, and ambient light sensors are a few examples.

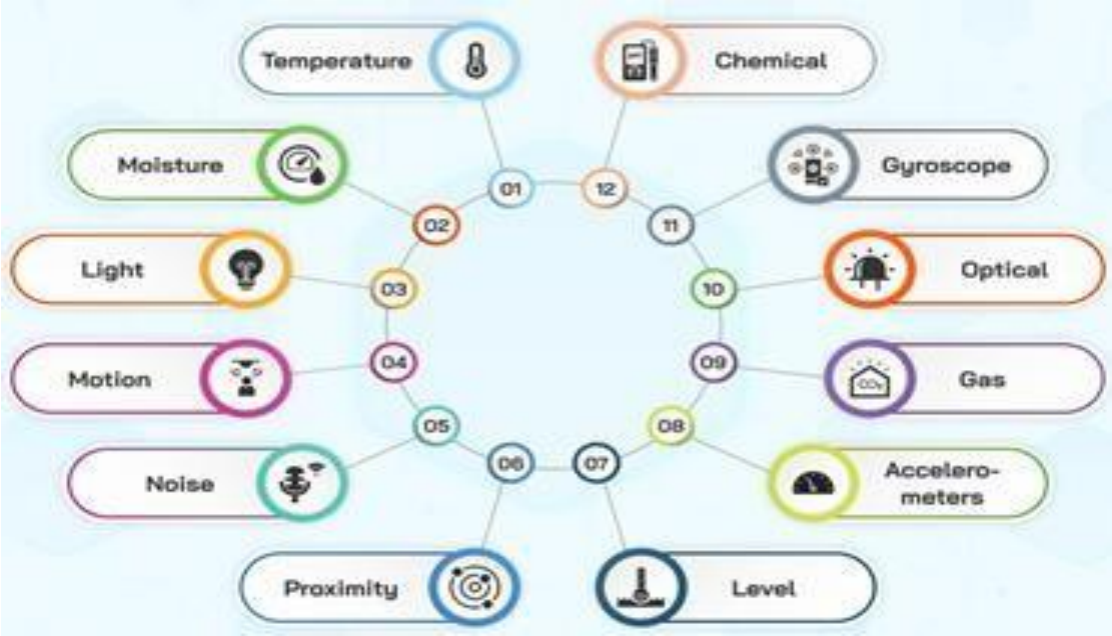

Figure 1.4 Classifications of sensor

Proximity sensor : Without physical touch, a proximity sensor may detect the existence or closeness of an item. Ultrasonic sensors, capacitive sensors, and inductive sensors are a few examples.

Accelerometer: Determines velocity changes or acceleration. used in projects including the evaluation of vibrations, direction detection, and recognition of motion.

Gyroscope : gyroscope detects rotational or angular movement. used in programmes for robots, virtual reality hardware, and systems for navigation.

Magnetic sensor : Measures and detects magnetic fields with a magnetic sensor.
Magneto resistive and Hall effect sensors are two examples.

Moisture sensor: Measures the relative humidity, or moisture content, of the air using a humidity sensor. Capacitive and resistive moisture sensors are a couple of examples.

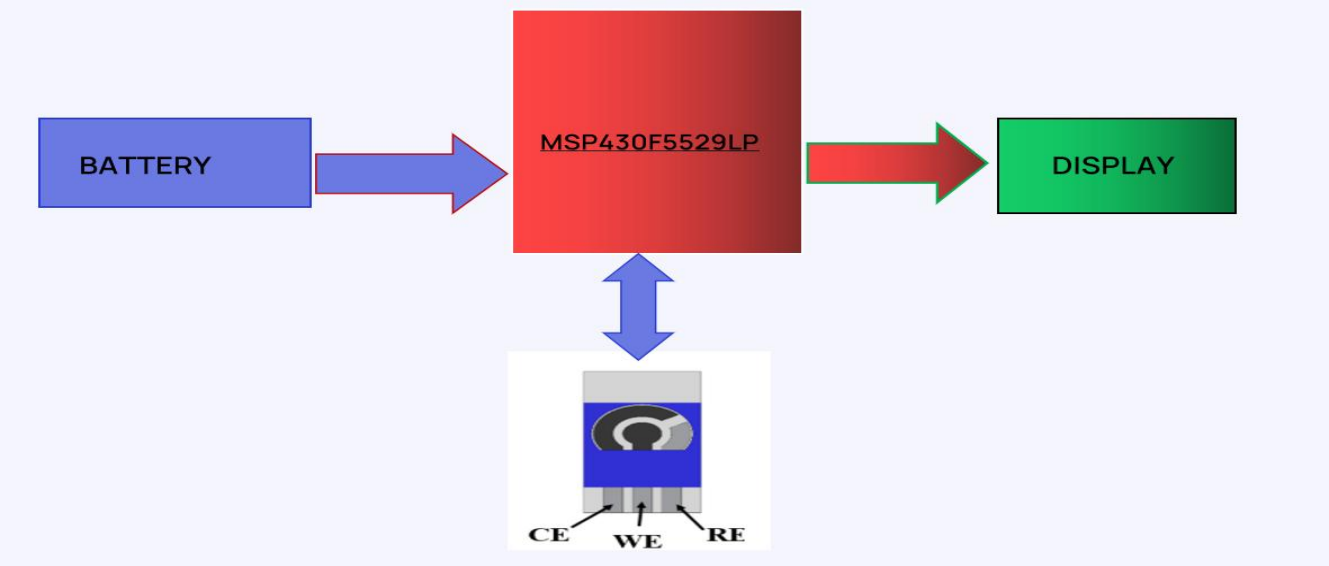

Figure 1.5 Block Digram of NPK micronutrients Detection system

1.8 Organization of thesis:

The main aim of this thesis is to design and implement an affordable, portable soil testing device that utilizes a paper-based, screen-printed electrochemical sensor in combination with the MSP430F5529 microcontroller. This system is specifically intended for measuring potassium ions (K^+) nitrogen ions (NO_3^-) potassium ions ($H_2PO_4^-$) in soil samples. The sensor incorporates a valinomycin-based ion-selective membrane applied to a screen-printed electrode, resulting in a straightforward yet efficient method for assessing soil nutrient levels. Real-time readings of potassium concentration are displayed on an LCD, enabling farmers to conveniently monitor soil fertility directly in the field. The thesis is structured into six chapters, each detailing a different aspect of the research and development process..

Component	**MSP430f5529L Connections**	**Interface Type**	**Function**
NPK Sensor	Analog pin	ADC pin	Measures NPK Ino and output voltage
LCD 16*2	GIPO Pin	Data pin	Display NPK %
Power Supply (battery/ USB)	Vcc and Gnd	Power	Power To Entire System
MSP430F5529L	Central Microcontroller Unit	ADC,GPIO,LCD Driver	**Sensor Data convert to %**

Table 1.2 Sytem Interface

Chapter 1:

In this chapter, introduction to the project thesis is given and discussion brief about environmental soil pollutions , N,P,K sensor , different detection method and types of sensors.

Chapter 2:

In this chapter, the literature survey on the conventional soil micronutrients detection methods, various soil macronutrients detection method , types of the sensor and it's characterization methods, types of electrode system and soil micronutrient syestem

Chapter 3:

This chapter tells about statement of problem, motivations, experimental setup , Details about used Tools such as CCS and ENERGIA.

Chapter 4:

This chapter is to known about sensor callibration and senso with system interface

Chapter 5:

This chapter discuss about the final result of this project work in disply Phosphorus macronutrients in system

Chapter 6:

This chapter provides an overview of the work completed, Conclusion and future work of my project.

2

LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 Literature survey:

This chapter gives the details about the work that has been done by different researches on the various NPK detection methods, different types of electrode system, electrochemical mechanism and types of macronutrients detection system and types of NPK sensor.

2.2 Overview of NPK Detection Methods:

Nitrogen (N), Phosphorus (P), and Potassium (K) are vital macronutrients that play a crucial role in supporting healthy plant development. To optimize fertilizer use and promote sustainable agriculture, it is important to accurately assess the levels of these nutrients in soil. Traditionally, methods such as spectrophotometry, atomic absorption spectroscopy (AAS), and inductively coupled plasma-optical emission spectrometry (ICP-OES) have been used in laboratories to measure NPK concentrations. While these techniques offer precise results, they tend to be costly, require significant time, and are not practical for direct application in the field.

To address these limitations, recent advancements have focused on developing portable and affordable sensor-based approaches for real-time NPK monitoring. Techniques such as colorimetric analysis, ion-selective electrodes (ISE), and various electrochemical sensing methods have gained attention for their suitability in on-site testing. Among these options, electrochemical sensors are particularly promising due to their excellent sensitivity, ability to selectively detect specific nutrients, and compatibility with compact, portable devices. This makes them well-suited for rapid and accurate soil nutrient analysis outside of traditional laboratory settings.

Inductively Coupled Plasma-Mass Spectrometry (ICP-MS):

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is an analytical technique that merges an inductively coupled plasma source with a mass spectrometer. In this process, the plasma generates extremely high temperatures that effectively ionize the atoms in the sample. These ions are then directed into the mass spectrometer, which separates and measures them according to their mass-to-charge ratio. This approach allows for the highly sensitive detection and quantification of a wide range of elements, even at trace levels, making ICP-MS a powerful tool for elemental analysis in various scientific fields

Neutron Activation Analysis (NAA):

Neutron Activation Analysis (NAA) is a precise and sensitive technique used to determine the presence and concentration of trace elements within a sample. The method involves exposing the sample to a stream of neutrons, which interact with the atomic nuclei and convert some of them into radioactive isotopes. As these newly formed isotopes return to a stable state, they emit gamma rays with energies that are unique to specific elements. By detecting and analyzing these gamma rays, it is possible to identify and measure the amounts of various elements in the sample. NAA is valued for its accuracy and ability to analyze very small quantities of elements without destroying the sample.

Laser-Induced Breakdown Spectroscopy (LIBS) :

Laser-Induced Breakdown Spectroscopy (LIBS) is an advanced analytical technique used to detect and measure the elemental composition of materials, including soil, rocks, plants, and metals, by using a high-energy laser pulse to generate a plasma on the sample surface. The emitted light spectrum from the plasma is analyzed to identify the elements present in the sample.

Atomic Absorption Spectroscopy (AAS)

Atomic Absorption Spectroscopy (AAS) is a method used to determine the presence and concentration of metal elements within a sample. In this technique, the sample is first converted into a gaseous state, allowing its atoms to be free. When a specific wavelength of light passes through these free atoms, they absorb some of the light. The amount of light absorbed at this wavelength is directly related to the quantity of the metal element in the sample. By measuring this absorption, AAS enables precise identification and quantification of metals present in various types of samples..

X-ray Fluorescence (XRF):

X-ray Fluorescence (XRF) is an analytical method that allows for the identification and quantification of elements present in a wide range of materials, such as soil, minerals, metals, plants, and building materials. This technique involves directing X-rays onto a sample, which excites the atoms within it. As these atoms return to their normal state, they release secondary, or fluorescent, X-rays. The energies of these emitted X-rays are characteristic of specific elements, enabling accurate determination of the material's elemental composition. XRF is valued for its ability to analyze samples without causing any damage to them

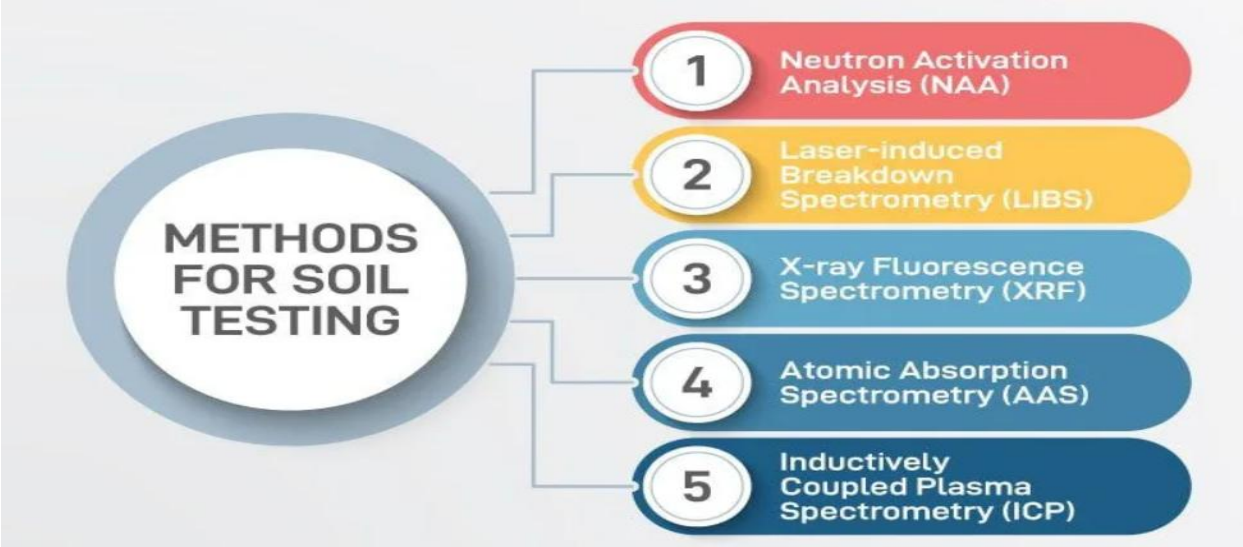

Figure 2.1different detection method

2.3 Different Types of Electrode Systems:

Electrochemical sensors for soil nutrient analysis typically rely on a three-electrode setup, which is fundamental for precise and selective ion detection. This arrangement consists of a working electrode, a reference electrode, and a counter electrode. The working electrode serves as the primary site for the electrochemical reaction. It is often modified with specialized materials or ion-selective membranes tailored to interact with specific target ions such as nitrate, phosphate, or potassium. This modification enhances the electrode's ability to selectively sense the nutrient of interest. The reference electrode provides a constant and well-defined potential, which is essential for accurate electrochemical measurements. Silver/silver chloride (Ag/AgCl) is a popular choice for the reference electrode due to its stable and reproducible potential in various environments

The counter electrode functions to complete the electrical circuit, allowing current to pass through the system during measurements. It balances the current generated at the working electrode, ensuring reliable sensor performance. Among the various electrode types used

in soil nutrient sensing, screen-printed electrodes (SPEs) stand out for their affordability and ease of mass production. Other commonly used electrodes include glassy carbon electrodes, valued for their chemical stability and conductivity, and metal oxide-based electrodes, which offer unique surface properties for enhanced sensitivity. These electrode systems have been widely adopted in research and practical applications for detecting essential soil nutrients

Elements	Abbreviation	From Adsorbed
Nitrogen	**N**	**NO-3**
Potassium	**K**	**HPO -2**
Phosphorus	**P**	**K+**
Sulphur	**S**	**SO-2**
Iron	**Fe**	**Fe+2**

Table 2.1 Elements of adsorbed

2.4 Electrochemical Mechanism:

Electrochemical sensing of NPK nutrients relies on interactions at the electrode surface, where either redox processes or ion-exchange reactions take place. The choice of detection technique depends on the type of nutrient being analyzed and the specific sensor design. Potentiometric sensors operate by measuring the electrical potential difference between electrodes, which changes in response to the concentration of a particular ion. This method is especially effective for ion-selective electrodes, as it does not require any current to flow, making it ideal for monitoring specific ions like nitrate, phosphate, or potassium. Amperometric sensors detect nutrients by applying a fixed voltage to the sensor and measuring the resulting current. This current is generated by redox reactions involving the

target analyte at the electrode surface. The magnitude of the current is directly related to the concentration of the nutrient, allowing for quantitative analysis.

Voltammetric techniques involve varying the applied voltage across the electrodes and recording the current response. As the voltage is swept, characteristic peaks in the current correspond to the presence and concentration of different analytes. This approach is particularly useful for detecting trace amounts of nutrients in complex soil samples due to its high sensitivity and ability to distinguish between multiple species.

Overall, these electrochemical methods offer reliable and sensitive detection of soil nutrients, even at low concentrations, making them highly suitable for agricultural applications where precise nutrient management is critical.

2.4.1 Electrochemical sensing techniques:

Electrochemical sensing techniques encompass a diverse range of methods that utilize electrochemical principles to detect and quantify analytes in various sample matrices. These techniques are widely used due to their high sensitivity, selectivity, simplicity, and compatibility with miniaturization for portable devices. Here are some common electrochemical sensing techniques;

2.4.2 Voltammetry :

Voltammetry measures current as a function of applied potential to characterize electroactive species. Common variants include cyclic voltammetry (CV), differential pulse voltammetry (DPV), and square wave voltammetry (SWV). A potential is applied to the working electrode, causing redox reactions at the electrode surface. The resulting current is measured and correlated with the concentration of the analyte.

2.4.3 Amperometry:

Amperometry measures current at a constant potential, typically after applying a voltage step or pulse. It is often used for detecting analytes that undergo rapid and irreversible electrochemical reactions. The potential is applied to the working

electrode, and the resulting current is measured over time as the analyte reacts at the electrode surface.

2.4.4 Impedance Spectroscopy:

Impedance spectroscopy measures the impedance across both IDE termical of an electrochemical system there impedance is function of frequency. Changes in impedance can be correlated with changes in the concentration or properties of the analyte. A sinusoidal voltage or current is applied to the electrochemical cell over a range of frequencies, and the resulting impedance spectrum is analyzed.

2.4.5 Potentiometry:

Potentiometry measures the potential difference between a reference electrode and a working electrode in a solution containing the analyte of interest. It is often used for ion-selective electrodes. The potential of the working electrode is adjusted until it matches the potential of the reference electrode, and the resulting potential difference is measured.

2.5. Colorimetric Detection methods:

Colorimetric arsenic detection is a method that uses color change to indicate the presence and concentration of arsenic in a sample. This technique is popular for its simplicity, cost-effectiveness, and ease of use, making it suitable for field testing and quick assessments.

1. **Solution preparation:** The sample (water, soil, or biological) is prepared by dissolving or suspending it in a solution.
2. **Color development:** The reaction between NPK and the reagents produces a color change. The intensity of the color is proportional to the NPK concentration in the sample.

3. **Color development**: The reaction between arsenic and the reagents produces a color change. The intensity of the color is proportional to the arsenic concentration in the sample.
4. .**Detection and quatification:** colorimetric arsenic detection is a valuable tool for quick, on-site testing and preliminary assessment of arsenic contamination, balancing ease of use and cost with the need for accurate and reliable detection.

3

MOTIVATION AND EXPERIMENTAL SETUP

3 PROPOSED SENSOR STRUCTURE, MOTIVATION AND EXPERIMENTAL SETUP MSP430

3.1 Statement of problem and Motivation:

Agriculture Agriculture is the cornerstone of India's economy, with a significant portion of the rural population relying on farming as their primary source of income. Despite its importance, farmers often struggle due to the absence of timely and precise information regarding soil health, especially concerning key nutrients like Nitrogen (N), Phosphorus (P), and Potassium (K). Traditional soil analysis methods are typically laboratory-based, costly, slow, and not easily accessible to smallholder farmers, particularly those living in remote regions. This lack of accessible testing often leads to improper fertilizer application, which can cause reduced crop yields, soil exhaustion, and increased farming expenses.

Having grown up in a farming family, I have seen firsthand the challenges faced by my community. The inability to quickly assess soil nutrient levels forces many farmers to rely on estimation when applying fertilizers, which can result in either insufficient or excessive use. This personal experience motivated me to pursue the development of a simple, affordable, and portable device that can accurately measure potassium (K^+) levels in soil using a paper-based electrochemical sensor. The goal of this project is to provide farmers with a practical tool that supports informed decision-making, encourages efficient fertilizer use, boosts crop output, and fosters sustainable agricultural practices.

The focus of this work is the creation of a cost-effective and portable system for detecting potassium in soil samples. The core of the system is a paper-based, screen-printed

electrochemical sensor featuring a valinomycin-based ion-selective membrane, which is sensitive to potassium ions (K^+). The sensor's signal is processed through an analog conditioning circuit and then interpreted by an MSP430F5529 microcontroller. Potassium levels are shown as a percentage on a 16x2 LCD, ensuring the device is straightforward and convenient for field use.

The entire system is engineered for ease of use and affordability, allowing farmers without specialized training to operate it confidently. The testing procedure involves extracting soil nutrients with a 0.01M $CaCl_2$ buffer solution, filtering the extract, applying it to the sensor, and directly reading the potassium percentage from the display.

3.2 All Experimental Tool and Software

3.2.1 Code Composer Studio software:

I used this tool to write code and design system for NPK micronutrients detection

Code Composer Studio (CCS) is an integrated development environment (IDE) developed by Texas Instruments (TI) for programming, debugging, and optimizing embedded applications on TI microcontrollers and processors. It is widely used in industries such as consumer electronics, industrial automation, communication infrastructure, and more.

3.2.2 Features of CCS

Integrated Development Environment (IDE)

Combines code editor, compiler, debugger, and project manager in one platform

Clean and user-friendly interface built on Eclipse framework**.**

Microcontroller-Specific Optimization

Specially designed for Texas Instruments (TI) devices like MSP430, C2000, TMS320 DSPs, and Sitara ARM processors.

Supports low-power development, especially ideal for MSP430-based applications like sensor systems

3.2.1 Energia software:

Supports low-power development, especially ideal for MSP430-based applications like sensor systems Energia is an open-source development environment designed to make programming Texas Instruments (TI) microcontrollers, especially the LaunchPad series, more accessible. It is inspired by the Arduino platform, offering a similar interface and programming style, which helps beginners and hobbyists quickly get started with embedded systems projects.

Main Features

Simple IDE: Energia provides a straightforward interface for writing, compiling, and uploading code, along with a built-in serial monitor for communication with connected devices.

Multi-Platform Compatibility: The software works on Windows, macOS, and Linux, allowing users to choose their preferred operating system.

Wide Board Support: Energia is compatible with various TI LaunchPad boards, such as the MSP430, MSP432, TM4C, C2000, and CC3200 families. Additional boards can be added through the board manager.

Arduino-Like Programming: The platform uses familiar functions and libraries, such as digitalWrite, digitalRead, and Serial.print, making it easy for those with Arduino experience to adapt.

Open Source and Community-Driven: Energia's source code is available to the public, and it benefits from community contributions and support.

Rapid Prototyping: The environment is designed to help users quickly develop and test interactive projects, supporting a range of sensors, actuators, and communication modules.

Easy Code Uploading: Code can be compiled and uploaded to supported boards with a single click, streamlining the development process.

Library Availability: Energia offers a variety of libraries for tasks such as wireless communication, sensor integration, and display control.

Common Uses

Education: Energia serves as a valuable tool for teaching microcontroller basics and embedded programming.

Prototype Development: It is frequently used for quickly building and testing new electronic ideas.

Internet of Things (IoT): The platform supports wireless modules, making it suitable for IoT projects.

Hobbyist Projects: Makers and DIY enthusiasts use Energia to create custom electronics with TI hardware.

3.2.3 Magnetic stirrer:

A magnetic stirrer in below Figure 3.2 is a laboratory device used to mix solutions and liquids efficiently and uniformly. It is widely utilized in chemistry, biology, and other scientific disciplines for tasks requiring consistent agitation over extended periods.

Here's a detailed description of its components, working principle, types, and applications.

Figure 3.3 Magnetic stirrer

3.2.3.1 Components:

Base Plate: The flat surface where the container or vessel with the liquid is placed.

Magnetic Stir Bar: A small, encapsulated magnet, usually coated with inert materials like Teflon (PTFE) or glass, to prevent chemical reactions with the stirred solution.

Motor and Magnet Assembly: Located beneath the base plate, it generates a rotating magnetic field. The motor drives the movement of this assembly.

Control Panel: Used to adjust the speed of rotation, and in advanced models, temperature settings if the stirrer includes a heating element.

Heating Element (Optional): Some magnetic stirrers, known as hot plate stirrers, include a heating element to simultaneously stir and heat the solution.

Working Principle:

The working principle of a magnetic stirrer is based on the creation of a rotating magnetic field. When the magnetic stir bar is placed in a container with liquid on the base plate, the rotating magnetic field generated by the motor and magnet assembly beneath the plate causes the stir bar to spin. This spinning action creates a vortex that effectively mixes the liquid in the container.

3.2.4 Weighing machine:

A weighing machine of Figure3.3 is also known as a scale, is an instrument used to measure the weight or mass of an object or substance. Weighing machines come in various types and designs, each suited for specific applications across diverse fields such as commerce, healthcare, research, and industry. Here's a detailed description of the components, working principle, types, and applications of weighing machines.

Figure 3.4 Weighing machine

3.2.4.1 Components:

Platform/Platter: The surface on which the object to be weighed is placed. It can be made of materials such as stainless steel, plastic, or glass, depending on the application.

Load Cell: A transducer that converts the mechanical force of the object's weight into an electrical signal. It is a critical component in electronic scales.

Indicator/Display: Shows the weight measurement, usually in digital format. It can be an LCD or LED screen.

Control Buttons: Used to operate the scale, including functions like tare (resetting the scale to zero), units conversion, and calibration.

Housing: The body or frame of the scale, which supports and protects the internal components.

Power Source: Can be batteries, AC power, or a rechargeable battery pack, depending on the design of the scale.

MSP430F5529L :-

The MSP430F5529 LaunchPad is a development platform from Texas Instruments designed for rapid prototyping and experimentation with the MSP430F5529 microcontroller. This board features a 16-bit RISC architecture, offering efficient performance with ultra-low power consumption, making it ideal for battery-powered and portable applications.

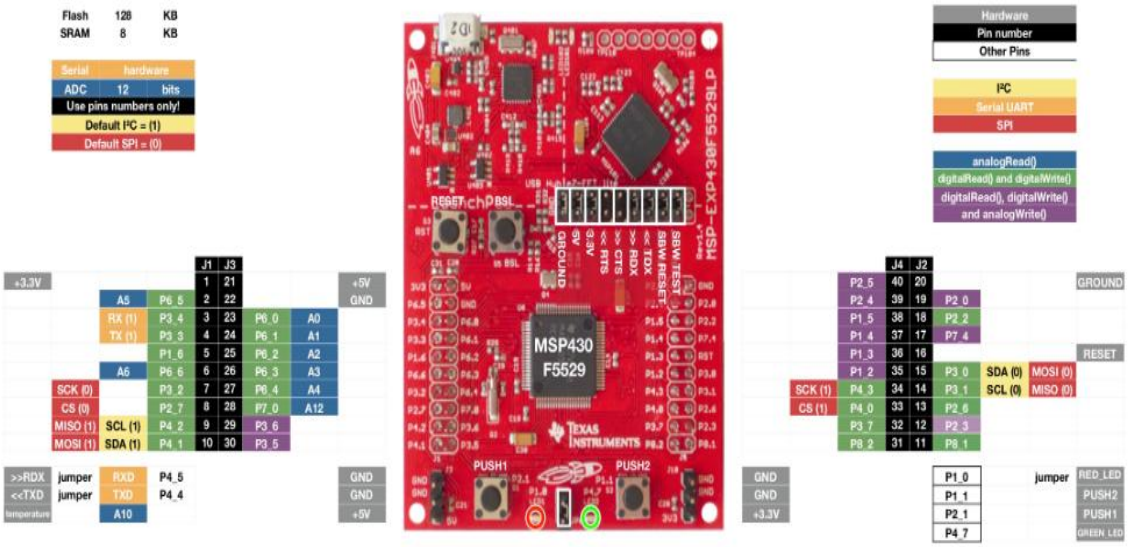

Figure 4.5 msp430 specification[https://embedded-lab.com/blog/tinkering-ti-msp430f5529/]

Features:

Microcontroller: MSP430F5529, operating up to 25 MHz

Memory: 128 KB Flash, 8 KB SRAM

Integrated Peripherals: Includes a 12-bit analog-to-digital converter (ADC), analog comparator, hardware multiplier, and multiple timers

Communication Interfaces: Supports USB 2.0, UART, SPI, and I2C for flexible connectivity with sensors and other devices

Power Supply: Can be powered via USB or external sources, with onboard voltage regulation for 3.3V and 5V rails

Pin Accessibility: Features dual rows of headers on both sides, providing access to all GPIO pins and peripheral functions

Pin Mapping and Functionality:

The board's pinout diagram provides a clear mapping of each physical pin to its corresponding microcontroller port and alternate functions. Pins are color-coded and grouped according to their major roles:

Digital and Analog I/O: Pins are marked for digital read/write and analog input/output functions, supporting flexible interfacing with external components.

Serial Communication: Dedicated pins for UART (TX/RX), SPI (SCK, MISO, MOSI), and I2C (SCL, SDA) allow easy connection to communication peripherals.

Special Functions: Certain pins are assigned to onboard buttons, LEDs, and jumper settings for quick testing and debugging.

Power and Ground: Multiple pins provide access to 3.3V, 5V, and ground for powering external circuits.

Ease of Use:

The LaunchPad is designed for user-friendly development. It includes onboard push buttons, LEDs, and a USB interface for programming and debugging. The clear labeling and color-coded pinout help users quickly identify the correct pins for their applications, whether for analog sensor input, digital control, or serial data communication.

Applications:

its robust feature set and low power operation, the MSP430F5529 LaunchPad is widely used in:

Sensor interfacing and data acquisition systems

Portable medical devices

Industrial automation

Educational projects and prototyping

LCD 16*2

A liquid crystal display (LCD) is a flat-panel electronic display that uses the light-modulating properties of liquid crystals in combination with polarizers to present visual information. Liquid crystals do not emit light directly; instead, they control the passage of light from a backlight or reflector to create images, either in color or monochrome.

Use

LCDs display information by electronically controlling each pixel, which is made up of liquid crystal molecules sandwiched between two transparent electrodes and polarizing filters. By applying varying electrical voltages, the orientation of the liquid crystal molecules changes, affecting how much light passes through each pixel. This allows the display to show numbers, letters, graphics, or video, depending on the application.

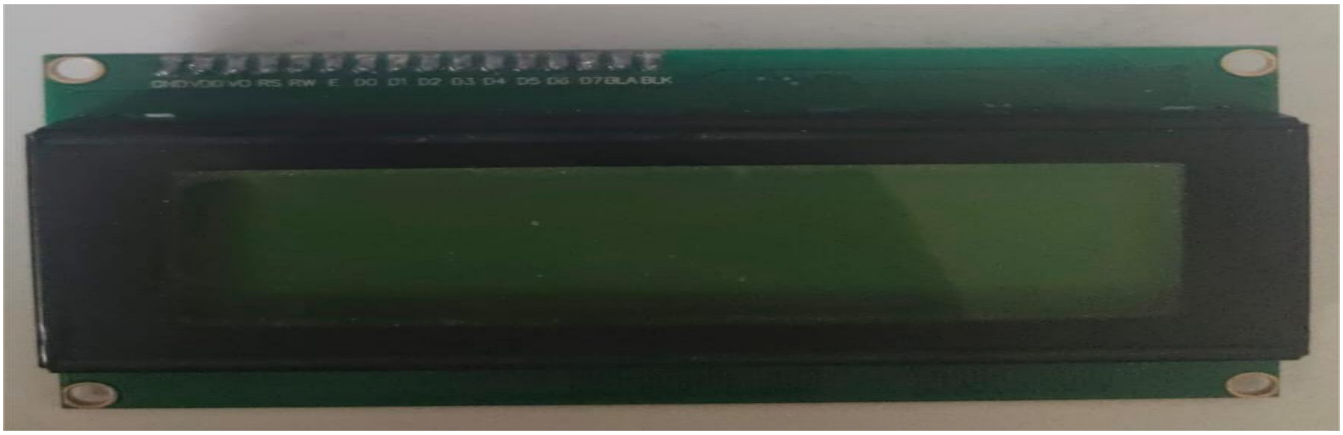

Figure 4.6 LCD 16*2

Applications

- LCD technology is widely used in many devices, including:
- Televisions and computer monitors
- Digital watches and calculators
- Mobile phones and tablets
- Instrument panels and automotive displays
- Digital cameras and camcorders

- Medical and industrial equipment
- Portable gaming devices

LCDs are popular because they are thin, lightweight, energy-efficient, and provide good image quality, making them suitable for both portable and stationary electronic devices

BATTERY

A 3V battery is a compact power source commonly used in small electronic devices. The most popular types are lithium-based coin cells (such as CR2032, CR2025) and cylindrical batteries (like CR123A).

Figure 4.7 Battery 3.7V

Types and Structure

Coin cell (button) batteries: Flat, round batteries (e.g., CR2032: 20mm diameter, 3.2mm thick) widely used in watches, calculators, remote controls, medical devices, and computer motherboards.

Cylindrical batteries: Slightly larger, used in devices needing more power, such as cameras, LED flashlights, and some industrial equipment.

Chemistry: Most 3V batteries use lithium manganese dioxide (Li-MnO_2) chemistry, offering high energy density, a stable 3V output, and a long shelf life (up to 10 years).

How It Works

The battery consists of a lithium metal anode (positive electrode) and a manganese dioxide cathode (negative electrode), separated by an electrolyte and a diaphragm.

During use, lithium ions move from the anode to the cathode through the electrolyte, while electrons flow through the external circuit, powering the device.

Applications

- Watches and calculators: Provide long-lasting, stable power for timekeeping and calculations.
- Remote controls and key fobs: Used for transmitting signals in car keys and home electronics.
- Medical devices: Power blood glucose meters, thermometers, and hearing aids.
- Motherboards: Maintain system settings in computers (CMOS memory).

4

NPK SENSOR CALLIBRATION AND MSP430 INTERFACE

4 NPK SENSOR CALLIBRATION AND MSP430 INTERFACE

4.1.For Sample Preparation:

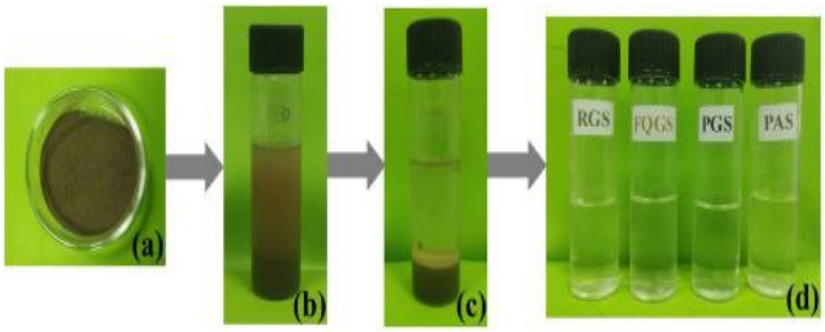

Figure 4.1 soil sample

Soil sample preparation detailed overview. (a) Collected soil sample 25 cm below the ground level from field. (b) Collected soil samples were air dried at room temperature, mixed thoroughly, crushed, and screened through a 2-mm mesh sieve. (c) Mix soil sample with 0.01-M CaCl2 solution with respective ratio and steer it for 45 min. (d) Allow to sett

4.1.9 Solution Preparation:

1. Soil Collection

- Collect soil from about 25 cm below the surface using a clean tool.
- Remove stones, roots, and visible debris.

2. Air Drying

- Spread the soil on a clean tray in a ventilated area.
- Let it air dry at room temperature for 4–5 days (avoid direct sunlight).

3. Crushing and Sieving

- Crush the dried soil gently with a mortar and pestle.
- Pass the soil through a 2 mm mesh sieve to achieve uniform particle size.

4. Mixing

- Thoroughly mix the sieved soil to ensure uniformity.
- If multiple subsamples are collected, combine and mix them for a composite sample.

5. Preparation of Soil Extract (Chemical Extraction)

- Weigh 5 grams of the prepared soil and place it into a clean beaker or flask.
- Add 10–30 mL of 0.01 M calcium chloride ($CaCl_2$) solution.
- Chemical required: Calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$), analytical grade.
- Preparation: Dissolve 1.47 g of $CaCl_2 \cdot 2H_2O$ in 1 liter of distilled water to make 0.01 M solution.
- Agitate the mixture on a shaker or stir vigorously for 45 minutes to extract exchangeable potassium and other ions.

6**. Settling**

- Allow the mixture to stand undisturbed for about 8 hours, so the soil particles settle and the supernatant becomes clear.

7. Filtration

- Filter the supernatant through filter paper (e.g., Whatman No. 2) to obtain a clear soil extract.

8. Sample Storage

- If not analyzing immediately, store the filtrate in a sealed container at 4°C.

9. Standard Solution Preparation (for Calibration)

- Prepare potassium standard solutions using potassium chloride (KCl).
- Chemical required: Potassium chloride (KCl), analytical grade.
- Preparation: Dissolve appropriate mass of KCl in distilled water to make standard solutions of known concentrations (e.g., 0.5 M, 1.0 M, 1.5 M, 2.0 M, 2.5 M).

10. Sensor Measurement

- Use the clear soil extract for measurement with the potassium sensor.
- For electrochemical calibration, use a redox agent such as potassium ferricyanide ($K_3[Fe(CN)_6]$) and a supporting electrolyte (KCl).
- Chemicals required: Potassium ferricyanide ($K_3[Fe(CN)_6]$), Potassium chloride (KCl).

9. Analysis

- Use the prepared soil extract for nutrient analysis (e.g., potassium detection using electrochemical sensors, atomic absorption spectroscopy, or colorimetric methods).

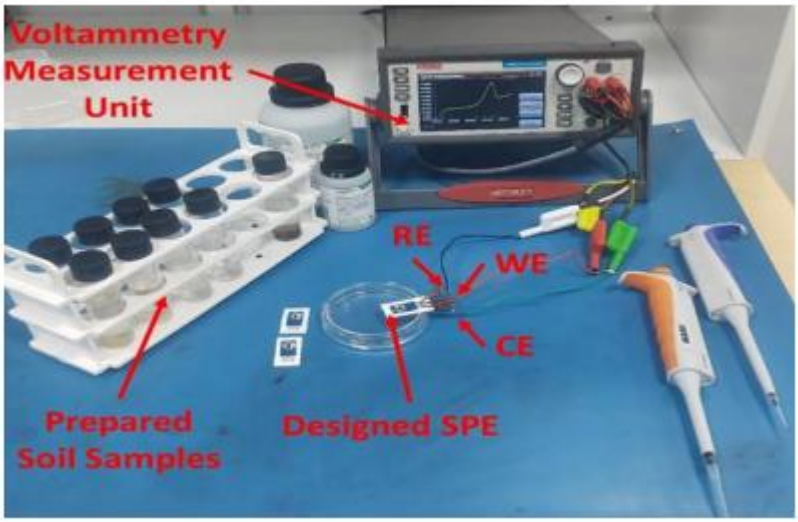

Figure 4.2 callibartion of Sensor

4.1.9.1 Calculation of NPK quantity: 1.Using ppm

Step 1: Converting ppm to Pounds per Acre

A common conversion for the top 6 inches (15 cm) of soil (assuming about 2 million pounds of soil per acre):

$$\text{lbs/acre} = \text{ppm} \times 2$$

Example:

If your soil test shows 50 ppm potassium (K),

$50 \times 2 = 100$ lbs K per acre

Step 2: Converting ppm to kg/hectare

For a 15 cm soil depth and average bulk density (1.3 g/cm³):

kg/ha = ppm × 2

Example:

30 ppm phosphorus (P):

$30 \times 2 = 60$ kg P per hectare

Step 3: Adjusting for Fertilizer Oxide Forms

Fertilizer labels for P and K are usually in oxide forms:

P as P_2O_5 (phosphate)

K as K_2O (potash)

Conversion factors:

To get P_2O_5 from P: multiply by 2.29

To get K_2O from K: multiply by 1.20

Example:

If you have 100 lbs/acre of K,

100 × 1.20 = 120 lbs K2O per acre

4.2 Characterization of Screen Printed Sensor Device:

After fabrication of Screen Printed Sensor sensor is ready to test, for that we used electrochemical test. The measurement of potential, charge, or current is employed in electrochemical characterisation to estimate an analyte's concentration or characterize its chemical reactivity. The fundamental electrochemical signals that serve as analytical signals are potential, charge, and current. Based on impedancemetry, amperometry, potentiometry, conductometry, voltammetry, and galvanic cell, electrochemical methods are frequently utilised. In electrochemical analysis, the flexible method of voltammetry collects currents as a function of changing voltages over time. Cyclic voltammetry is the optimum approach for the three electrode screen-printed devices in the voltammetry methodology. Figure 4.11 is showing characterization curve for CV as well as EIS.

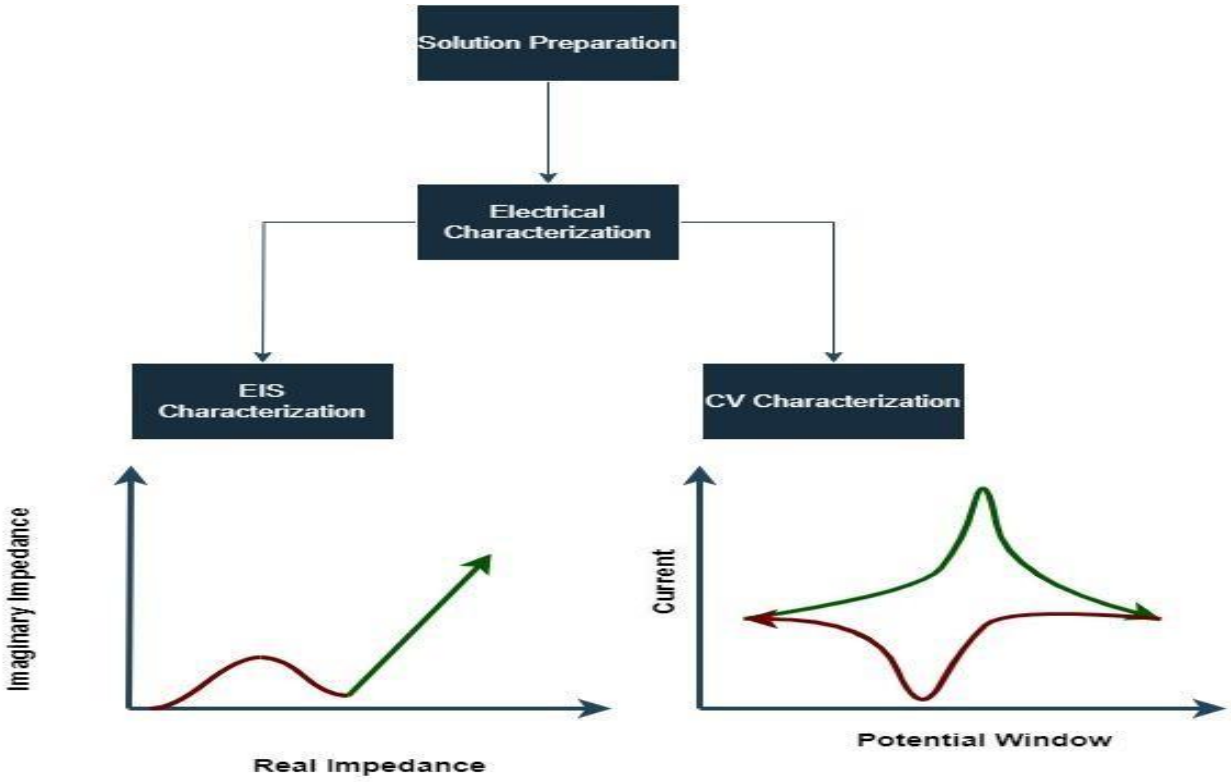

Figure 4.3 Block diagram of characterization

4.2.1 CV (Cyclic Voltammetry) characterization:

Cyclic voltammetry (CV), an efficient and well-liked electrochemical technique, is commonly used to investigate how molecular species are reduced and oxidised. The use of CV substantially facilitates the investigation of chemical reactions requiring electron transport, such as catalysis. Cyclic voltammetry has become a significant and well-liked electroanalytical technique in several areas of chemistry. It is frequently used to study redox processes, analyze electrochemical reactions between electrode surface atoms and investigated ions for understanding reaction intermediates to obtain stability of reaction products, obtain qualitative data on electrode reaction mechanisms, and determine qualitative features of the charge transfer reactions between electrolyte ions and electrons from the electrode surface.

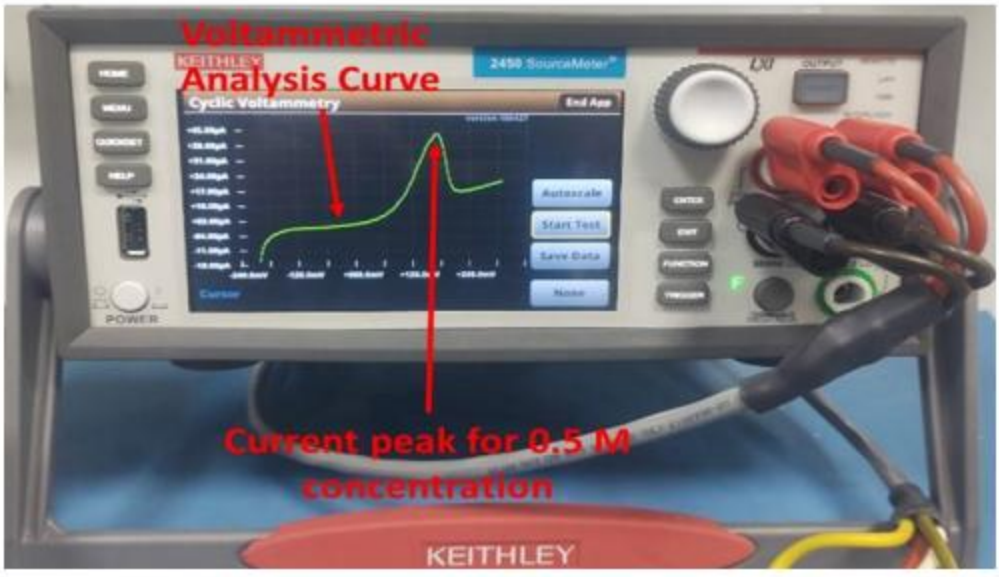

Figure 4.4 characterization of Phosphorus

So it is a good idea to study the redox reaction, which is important for comprehending how charge is stored in electrochemical systems. In cyclic voltammetry curve detail is represented by Figure 4.12, a three electrode electrochemical cell, the applied voltage to a working electrode is moved forward and backward while the current is being monitored. The working electrode's potential is ramped in the opposite direction by cyclic voltammetry (CV), a potentiometric dynamic electrochemical measurement, to return it to its initial potential. The model graph represented in below. These cycles could repeat again. A cyclic voltammogram displays current in relation to applied voltage.

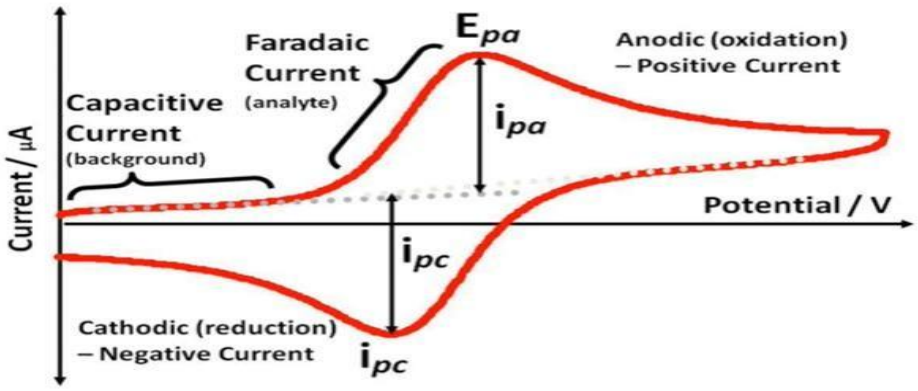

Figure 4.5 CV graph **[paper1]**

MSP430 INTERFACE WITH LCD 16*2

Connect the LCDs VCC and GND pins to the 5V supply and ground terminals of the microcontroller, respectively.

Attach a potentiometer between the 5V and ground lines, with its wiper connected to the LCD's contrast pin (V0), to allow for easy adjustment of display contrast.

Link the RW (Read/Write) pin directly to ground if you only need to send data to the display, which is the usual setup for most applications.

The Enable (E) pin should receive a brief pulse from high to low each time you want the LCD to register incoming data or commands.

Assign the LCD's data pins D4 through D7 to any available digital output pins on the MSP430F5529, and set these microcontroller pins as outputs in your program.

the 5V supply and the LED+ pin (pin 15) of the LCD, and connect the LED- pin (pin 16) to ground.

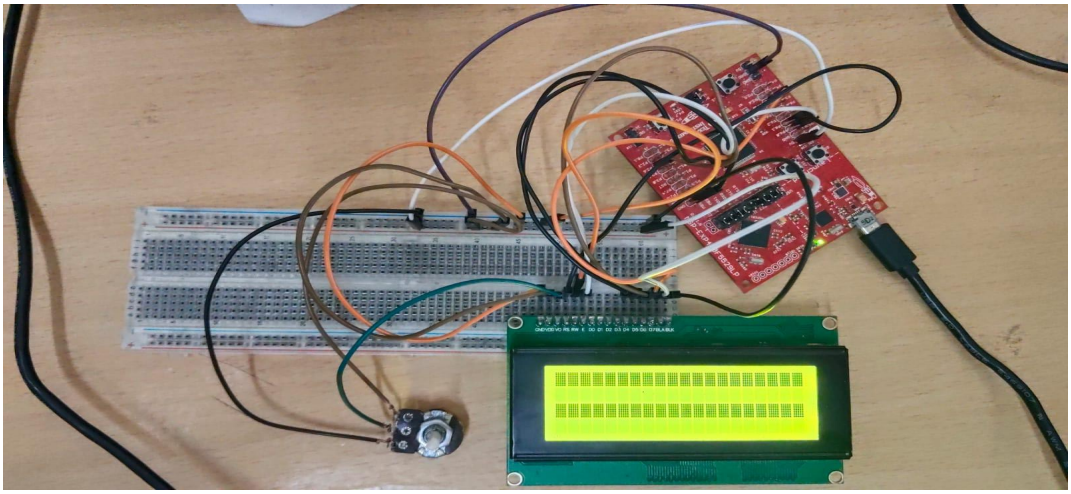

Figure 4.6 msp430 with lcd16*2

ADC TO DAC

1. Sensor Output (Analog Voltage)

The potassium ion sensor generates a voltage that reflects the concentration of potassium ions in the soil. This voltage is typically quite small and changes according to the amount of potassium present.

The MSP430F5529 microcontroller includes a 12-bit ADC module. This component takes the analog voltage from the sensor (between 0 and 3.3V) and converts it into a digital number. The conversion uses the formula:

ADC = (Vin/Vref) * 4095

- Vin is the voltage from the sensor.
- Vref is the reference voltage for the ADC, often set to 3.3V.
- 4095 is the highest value possible with a 12-bit ADC

5

SENSOR CALLIBRATION AND RESULTS

5 RESULT AND DICUSSIONS

Phosphorus (P) Detecation I Vs V:

The graph displays the relationship between the applied voltage (in volts) and the resulting peak current (in amperes) for a potassium ion sensor at different potassium concentrations. This type of plot is typically generated using cyclic voltammetry, a common electrochemical technique for analyzing ion-selective sensors.

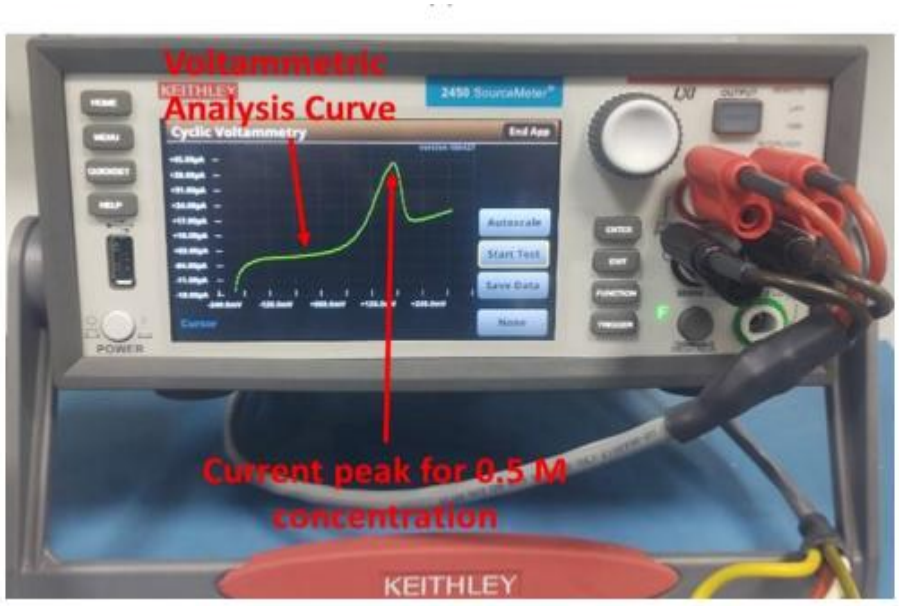

Figure 5.2 Phosphorus detect callibration [1]

- X-Axis (Applied Potential): This represents the voltage applied to the sensor, ranging from approximately -0.4 V to +0.6 V.
- Y-Axis (Peak Current): This shows the measured current response, with both positive and negative values indicating the direction of electron flow during oxidation and reduction reactions

System Detection Phosphorus : 0.2V

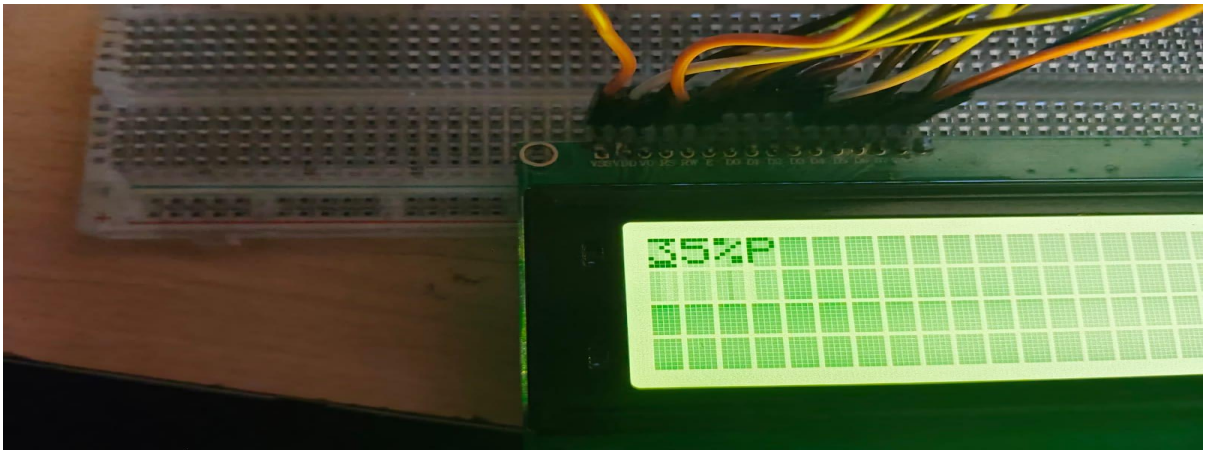

Figure 5.3 Phosphorus detect 0.2v

System Detection Phosphorus: 0.4V

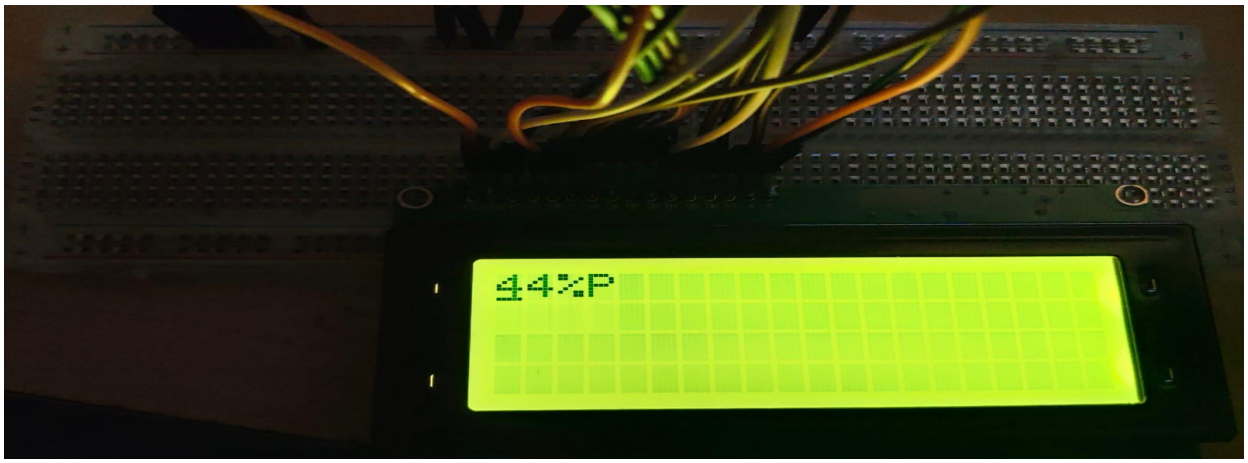

Figure 5.3 Phosphorus detect 0.4v

6

CONCLUSIONS AND FUTURE WORK

6 CONCLUSIONS AND FUTURE WORK

6.1 Conclusions:

This This thesis details the development and evaluation of a screen-printed interdigitated electrode (IDE) sensor, utilizing paper as the substrate, for straightforward, affordable, and user-friendly detection of NPK nutrients in contaminated soil. The primary goal of this project was to create a field-ready sensor that anyone—including those without technical training—could use to assess soil quality before planting crops. The sensor is designed for single-use, making it both economical and convenient for widespread adoption.

The NPK sensors were produced using screen printing technology, with the necessary masks designed in AutoCAD. The overall system incorporates the MSP430F5529 microcontroller and a 16x2 LCD display for real-time data presentation. For sensor characterization, electrochemical methods were employed, specifically cyclic voltammetry to monitor changes in current and electrochemical impedance spectroscopy (EIS) to observe impedance variations of the IDE sensor as NPK ion concentrations changed.

The unique design of the screen-printed IDE sensor, featuring an array of electrode "fingers," enables high sensitivity and selectivity for detecting soil nutrients, even at low concentrations. The sensor’s performance can be fine-tuned by adjusting parameters such as the length, width, spacing, and number of electrode fingers, which enhances its accuracy and reliability for long-term soil monitoring.

This system offers several advantages: it delivers immediate results regarding soil nutrient status, is cost-effective, and is easy to operate. By providing accurate information about soil micronutrient levels, the system empowers users to make informed decisions about fertilizer application, supporting better crop management and soil health. The integration of screen-printed IDE-based electrochemical sensors represents a significant advancement in the effective assessment and management of soil contaminants.

6.2 Future Scope :

By Looking ahead, several enhancements can make soil testing systems even more valuable and accessible for farmers. Incorporating advanced sensor materials, such as graphene, could significantly increase the sensitivity of the system, allowing for the detection of even trace amounts of nutrients with greater precision. Expanding the system to include additional sensors for measuring parameters like soil pH, moisture content, and the presence of toxic metals would provide a more comprehensive assessment of soil health.

Integrating artificial intelligence into the device could enable real-time analysis and personalized fertilizer recommendations, helping farmers make informed decisions about soil management directly in the field. By linking the system to a mobile application, farmers could receive instant feedback, tailored advice, and solutions to common agricultural challenges at any time. These improvements would not only enhance the accuracy and functionality of soil testers but also empower farmers with practical tools for increasing productivity and maintaining soil quality.

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